



## DEVICE CONVERTING THERMAL ENERGY INTO KINETIC ONE BY USING SPONTANEOUS ISOTHERMAL GAS AGGREGATION

My invention is a device converting thermal energy into kinetic one, related to the group of machines using four-phase basic thermodynamic processes like Carnot or Otto cycles. These devices need, for their operation, some kind of available outside heat source to be converted into kinetic energy. They consist  
5 of continuously lubricated moving parts, working in high temperatures, with quality deteriorating by usage and with noise emission.

My invention uses rarefied gas in a novel three-phase thermodynamic cycle, as shown in Fig.1 (p,v) diagram, of which the first phase is a spontaneous  
10 isothermal gas aggregation (0----1), equivalent to an ideal isothermal compression, the second phase is an adiabatic expansion (1----2), with work produced via an expander and the third one is an isobaric expansion (2----0) where, by means of an exchanger, the cooled gas is reheated again ( $q_2$ ) by cooling the ambient air. The shaded area below the adiabatic path (1----2)  
15 represents the work done at the expense of the internal thermal energy of the gas (Iso). The first phase arises when the gas passes through numerous special microscopic holes, with sizes comparable to the mean free path of the molecules, so that the latter do not collide with each other but only with the walls. I have thought up smart geometric shapes for these holes, like slot  
20 (Fig.2) and cone (Fig.3) with diverging inner surfaces, cavity (Fig.4) with segments of spherical inner surfaces, in order that the molecules may take advantage of a phenomenon (to be discussed further down the text), with the result that, during successive rebounds upon the inner walls, they tend to move forward, forming a small but discrete net flow from the input (i) to the output  
25 (o). The solid lines with the arrows show the central paths of the swarms of molecules. Under these special conditions the gas comes out of the holes spontaneously and isothermally, entering a room with increased density. Obviously, there result five advantages, by the use of my invention, i.e.

(1) energy production at the expense of the internal thermal energy of the gas, which then is reheated by the ambient air, (2) refrigeration for any domestic appliances, (3) no moving parts (except the expander), (4) high quality operation and (5) no noise.

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#### D e s c r i p t i o n .

Fig.5 (parallel view and cross section S-S) shows the device, consisting of a vacuum glass vessel (1) divided into two rooms (2) and (3) by a region (4) containing the microscopic holes assembly, consisting of a great number of  
10 holes, grouped into standard small modules (m), all arranged in a parallel layout as regards the gas flow. The closed circuit of the gas flow is supplemented with an adiabatic expander (5), within room (3) and a heat exchanger (6) in the return path of the gas from (3) to (2), transferring heat from the ambient air (7) to the gas with the help of ventilator (8). With suitable  
15 pressure difference between (2) and (3) an optimum flow is established; so that the device is continuously performing work, e.g. by means of a generator (9), coupled to the expander through a magnetic clutch (10) and a speed reduction gear (11) (if needed) and at the same time it offers cooling possibilities.

#### 20 T h e P h e n o m e n o n .

The operation of the device is based on a phenomenon observed at the time of the experimental research and evaluation of the external friction of gases [1], where it was shown that the molecules in a rarefied gas, rebounded from the inner walls of the container, under suitable vacuum pressure, do not exactly  
25 obey the so called cosine-law (uniform rebound to all directions) [2,p.27]; but, due to the existence of a molecular layer, adsorbed upon the walls, their path directions tend to slightly incline towards the perpendiculars to the walls, provided that the inner surfaces are quite smooth and the size of the container comparable with the mean free path of the molecules. Both of these properties  
30 are very important. The surface smoothness inside the holes must be perfect enough for the adsorption layer to cover the surface irregularities completely, otherwise the layer action is cancelled and the cosine-law prevails

again. Fortunately, nowadays a state-of-the-art value of surface roughness has been realized down to 1 nm, and even better [3], while in earlier decades values of less than 20 nm apparently had not been reached [4, p.622]. With regard to the size, I have taken the fundamental dimension of the holes  $\ell = 10 \mu\text{m}$ , which size is relatively easily realizable, happily in accordance with the technological progress of these days on Micro-Electro-Mechanical-Systems (MEMS) [5, p.56] and which is conveniently adaptable to the selected mean free path  $\lambda = 10 \mu\text{m}$ , as well as to the corresponding pressure [6, p.24], within the range of a well developed molecular layer. Finally, I consider worth mentioning that this peculiar behavior of the molecular layers offers a natural explanation of the repulsive forces between adjacent corpuscles in the Brownian motion phenomenon and also in the expansion of dust in the air [1, p.331].

#### Industrial Applicability.

The device has not been realized and tested experimentally. Nevertheless, its successful working ability is indeed proved indirectly, because it is based on the experimental and theoretical work mentioned in [1], as well as on a simulation method, assisted by electronic computer programs, to be described quantitatively as follows.

#### The Simulation Method.

In order to evaluate the amount of flow through the microscopic holes, it is necessary first to calculate the number of molecules emitted from any point A of the inner walls and fallen on any other point B as a function of the geometric parameters (dimensions; angles) of the holes.

Following the computer symbolism, let

$AB[\text{m}]$  = distance between two points A and B located anywhere on the inner walls of a hole.

$n_a [\text{sw}/\text{m}^3]$  = swarm of molecules per unit volume (volume density) around A  
 $dna [\text{sw}/(\text{m}^2 \cdot \text{s})]$  = swarm of molecules per unit area per unit time rebounded from A within an infinitesimal stereo-angle  $d\Omega [\text{sr}]$  towards B.

$v[m/s]$  = arithmetic mean velocity of the molecules

$c_{fa}, c_{fb}$  = cosines of angles  $\varphi_A, \varphi_B$  between AB and the perpendiculars on the respective infinitesimal facets  $ds_a$  and  $ds_b$  at A and B .

$na \cdot v/4 [sw/(m^2 \cdot s)]$  = molecules per unit area per unit time (surface density) rebounded from A to the inner hemisphere.

Then, in the absence of the adsorbed layer the cosine-law is expressed as follows [2,p.27]; (Pi means  $\pi$ ):

$$dna = na \cdot v / (4 \cdot \pi) \cdot c_{fa} \cdot d\Omega = na \cdot v / 4 \cdot c_{fa} \cdot c_{fb} / (\pi \cdot AB^2) \cdot ds_b$$

Or, in reduced form (divided by  $no \cdot v/4$  and multiplied by  $ds_a/ds_b$ )

$$dna \cdot ds_a / (no \cdot v / 4 \cdot ds_b) = wa \cdot c_{fa} \cdot c_{fb} / (\pi \cdot AB^2) \cdot ds_a \quad (1)$$

where  $wa = (na \cdot v / 4) / (no \cdot v / 4)$  = relative surface density on A,  $wo = no \cdot v / 4$  = input surface density. On integration of  $d\Omega$  over the inner hemisphere we obtain the basic quantity  $na \cdot v / 4$ . The factor  $c_{fa}$  expresses the cosine-law.

Now, in the presence of the adsorbed layer the cosine-law is to be modified, i.e. the factor  $c_{fa}$  should be substituted by [1, p.325]

$\{[1 - 2/3 \cdot f(p)] \cdot c_{fa} + f(p) \cdot c_{fa}^2\}$ , where  $f(p)$  is an increasing function with the pressure and with  $f(p)_{max} = 3/2$ , occurring at  $p = 1,918 \text{ mmHg}$ , which corresponds to  $(3/2 \cdot c_{fa}^2)$  as a substitute of  $c_{fa}$ . In that case

$$dna \cdot ds_a / (no \cdot v / 4 \cdot ds_b) = wa \cdot 3/2 \cdot c_{fa}^2 \cdot c_{fb} / (\pi \cdot AB^2) \cdot ds_a \quad (2)$$

This formula may be used at least also for pressures above 1.918 [mmHg], up to 23,2 [mmHg], which corresponds to the maximum thickness of the layer and beyond, given that it does not drop quickly after the maximum [1,p.305;Table]:

The forms of the holes are selected to possess some kind of symmetry so that the inner walls, as reflecting surfaces, may be divided into a large number (n) of strips (for the slots) and rings (for the cones and cavities), as shown in (12) of Figs 2,3,4. The same thing may be done on the input (i) and output (o) surfaces. Then, the relative density  $wa$  is constant along a strip or a ring. I have to remark that  $wa$ , when referred to the walls is an unknown, while when referred to the input surface it is known and equal to 1, and when referred to the output surface it is equal to the compression factor  $k$  between input and output. So, for each point B we are allowed to integrate (sum up) equations (1)

and (2) over each strip or ring, having previously expressed these equations as functions of the geometric parameters of the holes. After integration (addition) and by putting  $i$  for  $A_{i(=1,2,3,...n)}$  and  $j$  for  $B_{j(=1,2,3,...n)}$ , I rewrite equations (1) and (2) in a new form

$$\begin{aligned} 5 \quad sw_{ij} &= w_i * fbbp_{ij} \text{ (layer absent) } | \\ sw_{ij} &= w_i * fbbp_{ij} \text{ (layer present) } | \end{aligned} \quad (3)$$

where  $sw_{ij}$  = swarm of molecules per strip or ring per unit time, rebounded from the strip or ring containing  $A_i$  to  $B_j$  per unit area for  $B$ .

$fbbp_{ij}$  = transmission coefficients from a strip or ring  $i$  to point  $j$ , that are  
10 calculated as functions of the geometric parameters. In order to find the  $n$  unknown densities, I express, in the form of equation, the following equality which, under steady-state conditions takes place between the number of molecules fallen on any reflecting point  $j$  and the number  $w_j$  rebounded from the same point.

$$\begin{aligned} 15 \quad \sum_{i(=1,2,3,...n)} sw_{ij} [\text{reflecting surface}] + \sum_{i(=1,2,3,...n)} sw_{ij} [\text{input surface}] \\ + k * \sum_{i(=1,2,3,...n)} sw_{ij} [\text{output surface}] = w_j \end{aligned} \quad (4)$$

The first sum includes the unknown variables  $w_i$ . The second and third sums are known. In terms of equations (3) this equality, appropriately rearranged, becomes an  $n$ -variable linear equation for point  $j$ :

$$\begin{aligned} 20 \quad \sum_{i(=1,2,3,...j-1)} fbbp_{ij} * w_i + (fbbp_{jj} - 1) * w_j + \sum_{i(=j+1,j+2,...n)} fbbp_{ij} * w_i = \\ - \sum_{i(=1,2,3,...n)} fbbp_{ij} (\text{input}) - k * \sum_{i(=1,2,3,...n)} fbbp_{ij} (\text{output}) \end{aligned} \quad (5)$$

Finally, we have a system of  $n$   $n$ -variable linear equations, which may be solved with the help of Gauss algorithm [7,p.44-28].

### 25 Three examples .

Having established the numerical values of the  $n$  variables (densities), both for layer absence and layer presence conditions, it is easy to calculate the algebraic sum  $Fl(k)$  of flow of molecules through the input or output (it is the same), including all the path combinations. This net overall flow  $Fl(k)$  is a  
30 linear function of  $k$ , reduced to the unit of input surface density  $no * v/4$  and to the unit of area  $l_o^2$  (slots and cones)[Figs 2,3] and  $r^2$  (cavities)[Fig.4], ( $l_o = 2 * \ell$ ,  $r = \ell$ ).



Under layer absence and for  $k = 1$  we have  $Fl(1) = 0$ ; which complies with the cosine-law. Under layer presence and for  $k = 1$  we have  $Fl(1) = Flm(\text{maximum})$  and for  $k = km(\text{maximum})$  the flow stops, i.e.  $Fl(km) = 0$ . Under layer presence:

$$Fl(k) = Flm * (km - k) / (km - 1) \quad (6)$$

05  $Flm$  and  $km$  are also functions of the geometric parameters of the holes; i.e:  $li; \omega$  for slots and cones (Figs 2,3) and  $ac0, bd0$  for cavities (Fig.4). Optimum values:

Geometric parameters	slot	cone	cavity
$li(=li/lo)$	0,4	0,5	
$\omega[\text{rad}]$	1,4	0,8	
10 $ac0=bd0[\text{rad}]$			0,7227
Overall flow $Flm$	0,052	0,0218	0,1600
Compression factor $km$	1,1100	1,2500	1,2000

$km$  is found by the trial-and-error method or directly with the formula:

$$km = (A - Flm) / A \quad (A = \text{result of program with layer present, } k=1, \text{ zero input}) \quad (7).$$

15 Because of the great number of holes needed to achieve a somewhat remarkable result, I have organized the construction of the device in a form of small modules, as shown in Fig.6, consisting of a certain number ( $s$ ) of parallel very thin panels, say  $xe(=0,3\text{cm}) * ye(=2,1\text{cm})$ , each perforated with a number of holes ((13) for parallel slots of length all the way of the module's  $y$ -dimension, (14) for cones and cavities) and arranged in a pile(15) of height

$$H(s) = s * h + 2 * d \quad (8)$$

where  $h(=0,2\text{cm})$  = distance between successive panels,  $d(=1\text{cm})$  = input or output air ducts. The arrows show the path of the molecules. Suitable supporting rods ((16), solid lines) fix the panels in place. Along  $z$  we have ( $s$ ) holes in series and the molecule compression factor is  $k^s (=k_1 * k_2 * \dots * k_s)$ , ( $k_1=k_2=\dots=k_s=k$ ).

25 The number  $N_{\text{mod}}(=ax * ay)$  of holes per panel or of piles of holes per module is estimated to

	Slot	Cone	Cavity
$N_{\text{mod}} = ax * ay =$	$80 * (2\text{cm}/lo)$	$100 * 400$	$.66 * 400$

(9)

30 Two gases, Helium and Hydrogen, have been chosen as the most suitable for use with the device. The present examples will work with Hydrogen (mass  $g[\text{kg}] = 0,3347/10^{26}$ , arithmetic mean velocity  $v[\text{m/s}] = 1693$  [6,p.323]).

Now, Fig.7 (not in scale) shows a possible arrangement (18) of these modules (m) within a part  $O = 0,04241 \text{ m}^3$  ( $W=0,054 \text{ m}$ ) of a space (17) with dimensions  $X = 1 \text{ m}$  and  $D$  (diameter) =  $1 \text{ m}$ , which will contain the device of Fig.5(modules' assembly and expander). I have taken a limited value of  $O$  in order to accommodate a heat exchanger of reasonable size for the device. The arrows indicate the gas flow directions (i=input, o=output). Then, the number  $v(s)$  of modules contained in  $O$  and the whole number  $Np(s)$  of piles of holes is,

$$v(s) = O/(x_e*y_e*H(s)) \quad \text{and} \quad Np(s) = N_{\text{mod}}*v(s) \quad (10)$$

With regard to Fig.1: Work done per cycle(shaded area) [8,p.244]

$$Ls [\text{J/kg}] = R [\text{J/(kg*K)}]*T_o[\text{K}]/ \\ (n-1)*\{1-(1/k^s)^{(n-1)/n}\} \quad (11)$$

$$R [4,p.872] = 4124, \quad n [4,p.872] = 1,409$$

$T_o [\text{K}] = 253$  for slots,  $273$  for cones and cavities (see next paragraph).

In order to maximize the output power, the following expression  $a(k)$ , which is a product of three factors in Eqs (6),(8),(11),contained in the power output formula, must be maximized with respect to  $(k)$  and with  $(s)$  as a parameter, given that  $(s)$  may not exceed a limit  $(s_o)$ ,where the mean free path still remains "free" within the last holes,

$$a(k)=(k m-k)/(k m-1)/(s*h+2*d)*\{1-(1/k^s)^{(n-1)/n}\} \quad (12),$$

to find  $k=k_o$ ,  $s=s_o$ . Computed values of  $k_o$ ,  $s_o$ ,  $Fl(k_o)$ ,  $H(s_o)$ ,  $v(s_o)$ ,  $Np(s_o)$ ,  $l_{so}$  follow:

	slot	cone	cavity
$k_o$	1,05225	1,106	1,085
$s_o$	17	9	11
$Fl(k_o)$	0,0273	0,01256	0,0920
$H(s_o) [\text{cm}]$	5,4	3,8	4,2
$v(s_o)$	12465	17715	16028
$Np(s_o)/10^6$	997,2	708,6	423,1
$l_{so} [\text{J/kg}]$	566933	637950	630466

With plenty of margin  $(h)$  between successive panels and ample input-output air ducts  $(d)$ , the speed of flow outside the holes is kept within a few meters per second, practically eliminating friction losses and noise.

## Expander and Heat Exchanger .

The expander [9, p.449] is a single - stage reaction gas turbine, accommodated within the device (Fig.5, (5)). Its main features of interest here are the wheel diameter (D), the revolving speed (n) and the efficiency factor  $\beta_{exp}=0,825$ [9, p.271].

The exchanger[4,p.470-472] is constituted of 30 glass tubes (Fig.5,(6)) in parallel; 0,05m in diameter, 1m of length, situated along and around the device: The gas  $H_2$  passes (in laminar flow) through the tubes, while air (Fig.5,(7)) is forced (in turbulent flow) around them, in the opposite direction, as shown by the arrows, by means of the ventilator (Fig.5,(8)), with velocities 2 to 5 m/s.

In order to realize such a reasonable size of this component, it was necessary to let a greater temperature drop between warm air and cool  $H_2$  (40°C for slots, 20°C for cones and cavities). Fig.8 shows schematically [9, p.271] the heat exchanger and the corresponding flow diagram. The horizontal and slanted arrows show air- and  $H_2$ -flow; vertical arrows show heat-flow. The (computed) pressure drop, in the  $H_2$ -flow is too small to be taken into consideration.

Calculated values of (D), (n), and the working pressures and temperatures are as follows ( $c_v$  [kcal/(kg\*K)] = 2,41[4,p.871],  $e$  [kcal/J] = 0,2388/10<sup>3</sup>) :

	Slot	Cone	Cavity
EXPANDER D[m]-n[rev/min]	0,60-3630	0,41-3630	0,44-3630
Pressure input $p_1=p_o \cdot k_o^{\wedge}so$	1020*2,377	1121*2,48	1121*2,45
output $p_o$ [Pa]	1020	1121	1121
Temperature input $T_o(=T_d)$	253	273	273
Output $T_c=T_o-\beta_{exp} \cdot l_{so} \cdot e/c_v$	206,7	220,8	221,5
EXCHANGER Input air temp $T_a$	293	293	293
Output air temp. $T_b$	246,7(-26,3°C)	240,8(-32,2°C)	241,5(-31,5°C)
Input $H_2$ temp. $T_c$	206,7	220,8	221,5
Output $H_2$ temp. $T_d(=T_o)$	253	273	273
$T_a-T_b = T_d-T_c$	46,3	52,2	51,5
Air flow rate[m <sup>3</sup> /s]	0,95	0,66	0,77
Ventilator Power Invent.[w]	190	120	140



Hydrogen reheating thermal energy (Fig:1) [8, p.235]:  $q_2 = c_p \cdot (T_o - T_c)$

$(c_p \text{ [kcal/ (kg} \cdot \text{K)}] = 3,40 \text{ [4,p.871]})$	Slot	Cone	Cavity
$q_2 \text{ [kcal/kg]}$	157,42	177,48	175.10

#### N u m e r i c a l   R e s u l t s .

05 Finally, I proceed to calculate all the factors which determine the output power:

Loschmidt number [6, p.17] ( $p=1,02 \cdot 10^5 \text{ Pa}$ ,  $T=273 \text{ K}$ ) =

$$= 2,687 \cdot 10^{25} \text{ molecules/m}^3$$

Input pressure	$p_o \text{ [Pa]}$	1020	1121	1121
	$p_o \text{ [mmHg]}$	7,68	8,41	8,41

10 Input Temperature  $T_o \text{ [K]}$  253 273 273

Input Vol. Density no  $[\text{sw/m}^3]/10^{23}$  2,900 2,950 2,950

Hydrogen Velocity  $v \text{ [m/s]}$  1630 1693 1693

Input Surf. Density:

$$w_o = (n_o \cdot v / 4) [\text{sw}/(\text{m}^2 \cdot \text{s}) / 10^{23}] \quad 1182 \quad 1249 \quad 1249$$

15  $l_o \text{ [m]} = 20/10^6$   $r \text{ [m]} = 10/10^6$

Mass flow rate per hole: Slots and Cones  $gf \text{ [kg/s]} = g \cdot Fl(k_o) \cdot w_o \cdot l_o^2$   
Cavities  $gf \text{ [kg/s]} = g \cdot Fl(k_o) \cdot w_o \cdot r^2$

Total flow rate  $G \text{ [kg/s]} = gf \cdot N_p(so)$

Power output of expander  $I_{exp} \text{ [watt]} = \beta_{exp} \cdot l_{so} \cdot G$

20 Power output (pract.)  $I_{pr} \text{ [watt]} = I_{exp} - I_{vent}$

		Slots	Cones	Cavities
	$Fl(k_o)$	0,0273	0,01256	0,0920
	$gf \text{ [kg/s]} \cdot 10^{12}$	4,32	2,10	3,85
	$G \text{ [kg/s]} \cdot 10^3$	4,308	1,487	1,629
25	$l_{so} \text{ [J/kg]}$	566933	637950	630466
	$I_{exp} \text{ [watt]}$	2015	783	849
	$I_{vent} \text{ [watt]}$	190	120	140
	$I_{pract} \text{ [watt]}$	1825	663	709

#### C o n s t r u c t i o n   H i n t s .

30 Mass production can be achieved by the method of pressing [10,p.8-1], not excluding any other competent method. As construction material I would

propose glass; ceramic; silicon or the like; used in semiconductor technology:

Fig.9 shows a slot panel i.e. an arrangement of parallel triangular rods (19), forming slots (s) in between, lying on supporting rods (20) (cross-section  $T_1-T_1$ ) at suitable intervals. Cross section  $T_2-T_2$  of rods (19). The distance between successive panels is  $h=0,2$  [cm]. Both forms of rods can easily be manufactured in mass production with the active surface (b) made very smooth by advanced polishing processes [5, p.56].

The slot solution presents evident advantages over the other two solutions in, (a) manufacture, (b) greater output power per unit volume:

Fig.10 shows a cone panel (21) with cones (c) (cross section  $T_2-T_2$ ), arranged in series along x, lying on supporting rods (22) (cross-section  $T_1-T_1$ ), which are placed between adjacent cone series. Intervals between successive panels are equal to  $h=0,2$  [cm]. The cone active surface (b) is made very smooth. Fig.11 shows a possible scheme for cone panel fabrication, with the help of molds (2a,cylinders), (2b) and (p) as pressing means.

Finally, Fig.12 shows a cavity panel (23), carrying the holes with the active spherical surfaces (b) and the supporting rods (24) (cross sections ( $T_1 - T_1$ ,  $T_2- T_2$ )), carrying the active spherical surfaces (c). At suitable intervals along the rods(24), a contact rod (25) is made in place of the corresponding active surface (c), with elimination of the opposite side hole, in order that the panel is rigidly supported. Figs 13 and 14 show the forming of the active surfaces (b) and (c) of the cavity respectively, with the help of molds (3a),(3b),(3c,cylinders),(p) for Fig:13 and (4a);(4b);(p) for Fig:14: To achieve the exact spherical surface the molds should be equipped with tiny balls (s, dia.  $20\mu\text{m}$ ), with smooth spherical shape, like those used in miniature ball-bearings [11].

#### Computer Programs .

A  $3\frac{1}{2}$  in: floppy disc is available; containing the programs (written in Q-basic) of the present invention.

**R e f e r e n c e s .**

- [1] Annalen der Physik, W.Gaede, 41, S.289 – 336, 1913
- [2] Physik und Technik des Hochvacuums, A.Goetz,  
F.Vieweg, Braunschweig 1926.
- 05 [3] Optical Surfaces Ltd, Godstone Road Kenley  
Surrey, England CR8 5AA (correspondance).
- [4] Dubbel, Taschenbuch für den Maschinenbau I,  
Springer-Verlag, 13. Auflage, 1974.
- [5] IEEE Spectrum, Jan. 1999.
- 10 [6] Fundamentals of Vacuum Techniques,  
A. Pipko et al.,MIR Publishers,Moscow, 1984
- [7] Reference Data for Radio Engineers,  
H.W.Sams and Co, Inc.(ITT), 1969.
- [8] Engineering Thermodynamics,V.A.Kirillin et al.,  
15 MIR Publishers, Moscow, 1976.
- [9] Principles of Jet Propulsion and Gas Turbines, M.J.Zucrow,  
John Wiley & Sons,Inc.,New York, 1948.
- [10] Glass Engineering Handbook,G.W.McLelland,E.B.Shand  
McGraw Hill, Inc.,1984.
- 20 [11] Myonic GmbH, Miniature Bearings Division,  
Biel-Bienne, Swingerland.



Brief description of drawings (amended).

Page 1/7 (amended).

Fig. 1: Three – phase thermodynamic cycle diagram.

Fig. 2: Slot in face and side view. Diverging inner surfaces. Microscopic cross section (side view). Macroscopic length 20mm (30).

Fig. 3: Cone in face and side view.

Fig. 4: Cavity in face and side view.

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Fig. 5: Complete device of the invention (side view and cross section S-S).

Page 3/7 (amended).

Fig. 6: Small modules (m), panel (13) of parallel slots, cone and cavity panels (14), pile of panels (15).

Fig. 7: Arrangement (18) of modules (m). The arrows indicate the directions of the gas stream.

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Fig. 8: Heat exchanger diagram, corresponding flow diagram.

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Fig. 9: Slot panel (arrangement of parallel triangular rods (19), forming slots (s) in between).

Fig. 10: Cone panel (21).

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Fig.11: Possible scheme for cone panel fabrication.

Fig. 12: Cavity panel (23).

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Fig. 13: Forming of active surfaces on cavities.

Fig. 14: Ditto

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